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ORIGINAL ARTICLE

Test–retest reliability of morphological measurements of the mandible on cone-beam computed tomography-synthesized cephalograms

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KEYWORDS
reliability;
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Abstract *Background/purpose:* The current study aimed to determine the intra- and inter-rater, and intersession reliability of the determination of the morphological parameters of the human mandible using cone-beam computed tomography (CBCT)-synthesized cephalometric radiographs.
Materials and methods: CBCT data of 12 mandibles were obtained and used to generate synthetic cephalograms via a digitally reconstructed radiography (DRR) technique. Eleven landmarks describing the key morphological features of the mandible on each DRR-synthesized cephalogram were identified manually six times by one senior and one junior dentist. The operation was repeated 5 days later. Twelve parameters based on interlandmark line segments and their angles were calculated. Test–retest reliability was assessed in terms of intraclass correlation coefficient (ICC) and coefficient of variation (CV) using a two-way mixed-effects model. The paired-sample *t*-test was used to compare differences between examiners and sessions. A one-sample *t*-test was employed to assess whether the difference between the examiners was significantly different from zero.
Results: Very good intrarater (senior: ICC > 0.93; junior: ICC $= 0.78$ for CdP-GoP, ICC > 0.91 for other parameters), inter-rater (ICC $= 0.62$ for CdP-GoP, ICC > 0.84 for other parameters) and intersession reliability (ICC > 0.84 for all parameters and examiners; ICC $= 0.74$ for CdP-GoP for junior examiner) in measuring mandibular morphological parameters were found.
Conclusion: These results suggest that very good reliability could be achieved via manual identification of the anatomical landmarks without the effects of factors such as malpositioning of

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the head during imaging. Further investigations using the current DRR-based approach will be needed to evaluate the individual effects of these other factors on the morphological measurements.

Introduction

Cephalometric radiographs have long been used for orthodontic and surgical treatment planning, and for studying the dental–skeletal relationship.[1,2] The information of the growth patterns of the mandible related to orthodontic treatment or craniofacial surgery has also been quantified using cephalograms.[3,4] Cephalometric radiographs are easy to use and provide useful information to the dentists but they are limited to two-dimensional (2D) projective images of a three-dimensional (3D) object, i.e., the mandible, from the single X-ray source. Therefore, the same bone at different distances from the image plane would produce bone images of different sizes, position, and intensity, leading to errors in measurements and thus the subsequent interpretations.[5,6]

There are several factors that can affect cephalogram-based morphological measurements of mandibular growth, including identification of bony landmarks, experience of the examiner, superimposition of craniofacial structures, and positioning of the head during imaging.[6,7] These factors often have coupled effects on the morphological measurements. For example, both head rotation and superimposition of the craniofacial structures with the mandible increase the difficulty in identifying the bony landmarks, leading to errors in the subsequent morphological measurements.[8,9] Although knowledge of the effects of these individual factors helps to identify the measures to take to minimize the measurement errors, this has not been achieved because these factors are not separable in real life conditions. Therefore, measurement errors remain the major source of uncertainties in various applications such as the diagnosis, planning, and evaluation of treatment. Moreover, because these morphological measurements may be taken by the same and by different clinicians of different experiences, and at different stages in the management of one patient, it is also necessary to determine if the measurements used are reliable both within (intrarater) and between clinicians (inter-rater), and between sessions (intersession).

Studies on the reliability of mandibular morphological measurements on planar radiographs have been limited. Most previous studies have focused the intra- and inter-rater reliability of the identification of the anatomical landmarks that define the mandibular morphology on planar radiographs in terms of intraclass correlation coefficient (ICC) values.[10,11] However, few studies have evaluated quantitatively the intra-, inter-rater, and intersession reliability of the determination of morphological parameters of the human mandible from planar radiographs. Furthermore, no study has quantified the effects of the identification of bony landmarks on the reliability of morphological parameter determination without the effects of other factors such as superimposition of craniofacial structures, and positioning of the head during imaging. In recent years, cone-beam computerized tomography (CBCT) has been used for routine evaluations of orthodontic cases[12–14] and implant cases.[15,16] By taking advantage of computer simulations, the repeated planar measurements can be made on 2D digitally reconstructed radiographs (DRR) synthesized using the CBCT data. This technique has been used to study the morphology of the human ankles[17] and canine hips.[18] With this technique the effects of the identification of bony landmarks on the reliability of morphological parameter determination could be studied without the effects of other factors such as superimposition of craniofacial structures, and positioning of the head during imaging.

The purpose of the current study was to determine the intra-, inter-rater, and intersession reliability of the determination of the morphological parameters of the human mandible using CBCT-synthesized cephalometric radiographs.

Materials and methods

Participants

Twelve participants (age: 37 ± 7 years old; 6 males, 6 females) scheduled for orthodontic evaluation participated in the current study. They were free from any temporomandibular diseases and gave informed written consent as approved by the Institutional Review Board. Each mandible was scanned by a CBCT system (i-CAT, Xoran Technologies, Ann Arbor, MI, USA) in the National Taiwan University Hospital, with a slice thickness of 0.4 mm and an intraslice pixel size of 0.4 mm × 0.4 mm.

Generation of synthetic radiographs

The mandible within the CBCT volume was semi-automatically segmented using a region growing with thresholds method (Amira, Visage Imaging Inc., Berlin, Germany; Fig. 1A). The segmented volume of the mandible was then used to reconstruct polygonal-meshed surface model of the mandible (Fig. 1B). On each mandible model an anatomical coordinate system (ACS) was defined by the epicondyles and the centers of the edges of the two central incisors, which were digitized manually using a self-developed program. The mandibular ACS originated at the midpoint between the epicondyles, with the *z*-axis directed to the right epicondyle, the *y*-axis directed superiorly and normal to the plane defined by the *z*-axis and the midpoint of the centers of the central incisor edges, and the *x*-axis as the cross-product of *y*-axis and *z*-axis, and directed anteriorly.[19]

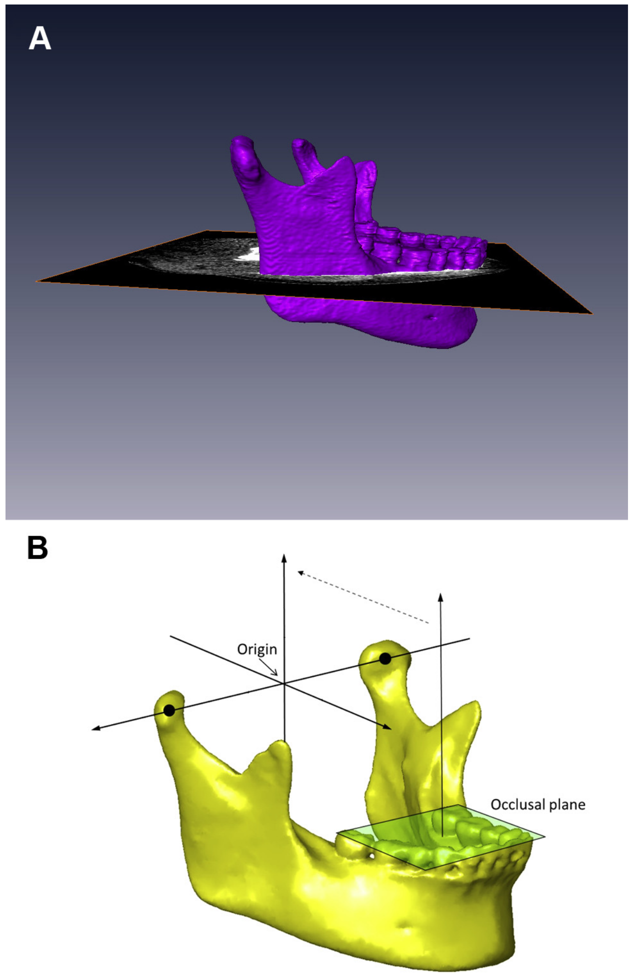

Figure 1 (A) The surface model of the mandible was reconstructed from the semiautomatically segmented processing using a region-growing with thresholds method in Amira. (B) On each mandible model an anatomical coordinate system (ACS) was defined by the epicondyles and the centers of the edges of the two central incisors, which were digitized manually using a self-developed program.

The volume of the mandible was imported into a self-developed software program for generating synthetic cephalograms. The formation of the synthetic cephalogram image of the mandible was achieved using a digitally reconstructed radiography (DRR) generation technique,[20] which modeled the radiography system as an ideal perspective projection of a point source X-ray through the bone onto the image plane. In the current study, the radiographic projection model was set up to model a commercially-available cephalogram system used in the authors' hospital, namely an Orthoceph OC l00 X-ray system (Instrumentarium Corporation, Imaging Division, Tuusula, Finland), with a pixel size of 0.29 mm $\times$ 0.29 mm. The principal axis of the projection was defined as the line connecting the most prominent points on the medial surfaces of the bilateral condyles. The X-ray source was positioned on the right side of the midsagittal plane of the mandible at a distance of 1520 mm, whereas the image plane was located 152 mm away from the left side of midsagittal plane, opposite the source. The DRR cephalograms were generated by casting rays from the point source X-ray of the radiographic projection model through the CT volume of the mandible using a ray-tracing with trilinear interpolation method.

Repeated measurement of morphological parameters

Two dentists from National Taiwan University Hospital, Taipei, Taiwan, one with 11 years of experience and the other with 1 year of experience, participated in the current study as examiners. Each of the synthetic cephalograms of the 12 participants was presented to the two examiners in a random order. The examiners were asked to identify 11 landmarks that describe the key morphological features of the mandible (Table 1 and Fig. 2) using the mouse pointer with the assistance of a graphics-based user interface implemented in MATLAB (MathWorks Inc., MA, USA) on a personal computer. Each anatomical landmark was identified six times (trials) by each examiner (Fig. 2). The retest was performed at approximately the same time of the day on a subsequent day within a period of 5 days after the first session, following the same test procedure.

For each measurement the identified landmarks were used to define line segments, length changes, and angular changes which were used to calculate a total of 12 morphometric parameters describing the growth of the mandible (Table 2), similar to parameters considered in a previous study.[21]

Table 1 Anatomical landmarks on the mandible utilized in this study.

Bony landmark	Definition
Cd	*Condyle*: The most protruding point on the top of the mandibular condyle.
CdP	*Condyle posterior point*: The most posterior protruding point of the mandibular condyle.
GoP	*Gonion posterior point*: The most posterior protruding point of the ramus above the gonion.
Go	*Gonion*: The midpoint of the contour connecting the ramus and body of the mandible.
GoA	*Gonion anterior point*: The most protruding point of the mandible before gonion.
Me	*Menton*: The center of the inferior border on the mandibular symphysis.
Pog	*Pogonion*: The most anterior point on the contour of the chin.
Gn	*Gnathion*: The center of the inferior border on the mandibular symphysis.
B	*B point*: The innermost point on the contour of the mandible between the incisor and the bony chin.
Li	*Lower central incisor edge*: Incisal edge of the mandibular central incisor.
CP	*Coronid process*: The top point of the Coronoid.

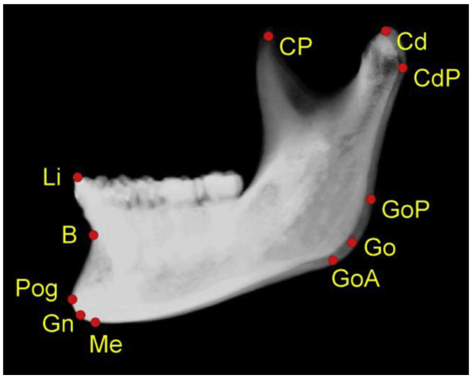

Figure 2 The illustration of the mandibular bony landmarks on cone-beam computed tomography-synthesized cephalogram. The definition of each landmark and parameter can be referred to in Tables 1 and 2.

Table 2 Parameters of anatomical landmarks on the mandible utilized in this study.

Parameters	Definition
Cd-Gn, Cd-B, Cd-Li	Parameters related to the changes of the total mandibular length
Go-Pog, Go-Gn, Me-GoA	Parameters related to the changes of the mandibular corpus length
Cd-Go, CdP-GoP, Cd-CP	Parameters related to the changes of the mandibular ramus length
Li-Me	The anterior length of the mandible
Cd-Go-Gn	Goion angle
Go-Gn-Li	The angle of the lower anterior teeth

Statistical analysis

The values of the morphometric parameters measured from each of the 12 radiographs were ensemble-averaged across all participants for each examiner, giving means and standard deviations (SD). Test–retest reliability was assessed in terms of coefficient of variation (CV) and ICC using a two-way mixed-effects model ($ICC_{3,1}$) for intraexaminer reliability, and a two-way random-effects model ($ICC_{2,k}$) for interexaminer reliability.[22] ICC values ranging from 0.81 to 1.00 indicate very good reliability; 0.61–0.80 good reliability; 0.41–0.60 moderate reliability; 0.21–0.40 fair reliability; and below 0.2 poor reliability.[23] Paired-sample t-test was used to address the differences of measurements between examiners and sessions. Bland and Altman plots were used to visualize the difference between examiners against the corresponding averaged value from the two examiners for all synthetic radiographs.[24] A one-sample t-test was employed to assess whether the difference between the examiners was significantly different from zero. A significance level of 0.05 ($\alpha = 0.05$) was set for all tests. All statistical analyses were performed using SPSS version 19.0 (IBM Corp., Armonk, NY, USA).

Results

Very good intrarater reliability for all parameters was found by both examiners except for CdP-GoP measured by the junior examiner (Table 3). The ICC values for all parameters were >0.93 for the senior examiner whereas those for the junior examiner were mostly >0.91 except for the ICC of 0.78 for CdP-GoP (Table 3). Mean CV values were <0.13 for both examiners (Table 3).

Very good inter-rater reliability was found for most parameters with ICC values >0.84, slightly smaller than most of the intrarater ICC values (Table 3). Only good reliability

Table 3 The values of mean and standard deviation of each mandibular morphometric parameter are listed. The intrarater (ICC_1) and inter-rater (ICC_2) correlation coefficient and coefficient of variation (CV) were also reported to address the reliability of the measurements within/between senior and junior examiners. The P values calculated from the paired-sample t-test indicate the differences in the measurement between examiners if the P values were $<\alpha$ value set at 0.05.

	Senior			Junior			Inter-rater	
	Mean (SD)	ICC_1	CV	Mean (SD)	ICC_1	CV	ICC_2	P*
Cd-Gn	111.67 (5.12)	0.99	0.05	109.63 (5.53)	0.98	0.05	0.96	<0.001**
Cd-B	99.35 (4.16)	0.99	0.04	98.11 (4.27)	0.95	0.04	0.96	<0.001**
Cd-Li	93.39 (4.61)	1.00	0.05	92.10 (4.12)	0.97	0.04	0.96	<0.001**
Go-Pog	72.63 (4.71)	0.99	0.06	72.41 (4.78)	0.95	0.07	0.97	0.392
Cd-Go	59.86 (4.83)	0.99	0.08	60.78 (3.87)	0.92	0.06	0.95	0.002
Go-Gn	71.61 (4.53)	0.97	0.06	70.10 (4.85)	0.95	0.07	0.92	<0.001**
CdP-GoP	39.05 (3.96)	0.93	0.10	43.14 (3.49)	0.78	0.08	0.62	<0.001**
Me-GoA	60.77 (4.96)	0.95	0.08	58.49 (5.52)	0.94	0.09	0.84	<0.001**
Cd-CP	34.94 (2.90)	0.98	0.08	34.74 (2.82)	0.91	0.08	0.97	0.269
Li-Me	38.94 (5.14)	1.00	0.13	37.98 (5.07)	0.98	0.13	0.99	<0.001**
∠Cd-Go-Gn	116.31 (6.49)	0.99	0.06	113.89 (6.28)	0.96	0.06	0.95	<0.001**
∠Go-Gn-Li	79.27 (8.47)	0.99	0.11	81.02 (8.88)	0.97	0.11	0.98	<0.001**

*P values of the paired-sample t-test of the measurements between senior and junior.
** Significant difference in the measurement between examiners.
ICC_1 = intrarater correlation coefficient; ICC_2 = inter-rater correlation coefficient.

was found for CdP-GoP (ICC = 0.62; Table 3). There were no significant differences between the examiners except for Go-Pog (P = 0.392) and Cd-CP (P = 0.269; Table 3). There were no systematical biases between examiners on most parameters, except Go-Pog, Cd-Go, and Cd-CP (Fig. 3).

Very good intersession reliability was found in both examiners for most parameters with ICC values >0.84. Only

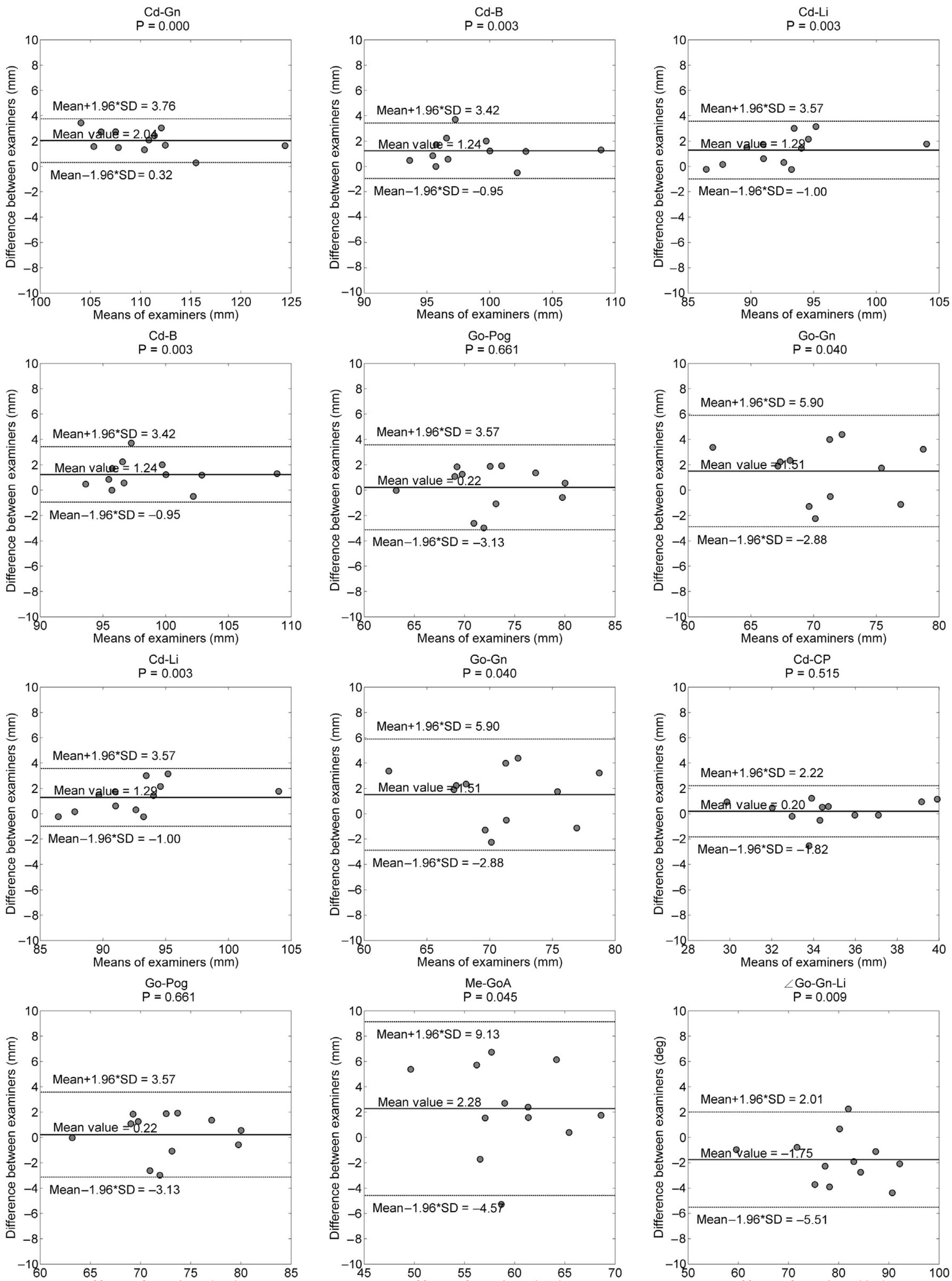

Figure 3 Bland and Altman plots of each mandibular parameters of the inter-rater. The unbroken lines indicate the mean values of examiners. The broken lines indicate the 95% confidence intervals of the difference between examiners.

Table 4 The values of mean and standard deviation of each mandibular morphometric parameter measured by examiners are listed. The values of intersession correlation coefficient (ICC) and coefficient of variation (CV) are also listed to test the reliability between sessions within senior and junior individually. P values <0.05 indicate significant differences in the measurements between sessions.

	Senior					Junior				
	$Mean_1$ $(SD)_1$	$Mean_2$ $(SD)_2$	ICC	CV	P	$Mean_1$ $(SD)_1$	$Mean_2$ $(SD)_2$	ICC	CV	P
Cd-Gn	111.67 (5.12)	111.23 (5.31)	0.96	0.05	0.037*	109.63 (5.53)	109.66 (5.50)	0.98	0.05	0.858
Cd-B	99.35 (4.16)	99.01 (4.23)	0.94	0.04	0.100	98.11 (4.27)	97.61 (3.72)	0.96	0.04	0.022*
Cd-Li	93.39 (4.61)	93.59 (4.80)	0.94	0.05	0.501	92.10 (4.12)	91.89 (3.91)	0.98	0.04	0.161
Go-Pog	72.63 (4.71)	72.22 (7.35)	0.95	0.08	0.508	72.41 (4.78)	74.56 (4.17)	0.92	0.06	<0.001*
Cd-Go	59.86 (4.83)	59.77 (6.49)	0.88	0.10	0.883	60.78 (3.87)	59.32 (4.95)	0.84	0.07	0.002*
Go-Gn	71.61 (4.53)	71.01 (7.75)	0.92	0.09	0.416	70.10 (4.85)	72.56 (4.42)	0.92	0.07	<0.001*
CdP-GoP	39.05 (3.96)	38.98 (4.98)	0.89	0.11	0.824	43.14 (3.49)	41.42 (3.99)	0.74	0.09	<0.001*
Me-GoA	60.77 (4.96)	60.33 (7.91)	0.90	0.11	0.563	58.49 (5.52)	60.17 (5.10)	0.85	0.09	<0.001*
Cd-CP	34.94 (2.90)	35.34 (2.89)	0.94	0.08	0.005*	34.74 (2.82)	34.38 (2.97)	0.96	0.08	0.022*
Li-Me	38.94 (5.14)	39.40 (6.12)	0.97	0.14	0.227	37.98 (5.07)	38.17 (5.15)	1.00	0.13	0.142
∠Cd-Go-Gn	116.31 (6.49)	116.22 (6.58)	0.98	0.06	0.730	113.89 (6.28)	112.41 (6.14)	0.97	0.06	<0.001*
∠Go-Gn-Li	79.27 (8.47)	80.97 (15.04)	0.89	0.15	0.244	81.02 (8.88)	79.92 (10.9)	0.94	0.12	0.194

* Significant difference in the measurement between examiners.

good reliability was found for CdP-GoP (ICC = 0.74) measured by the junior examiner (Table 4). Mean CV of both examiners were <0.3 (Table 4). Between sessions, there was no significant difference in most parameters for the senior examiner except the Cd-Gn (P = 0.037) and Cd-CP (P = 0.005), but there were significant differences in most parameters for the junior examiner (Table 4).

Discussion

The current study aimed to determine the intra-, inter-rater, and intersession reliability of morphological measurements of the mandible on CBCT-synthesized cephalometric radiographs. The results showed that both the intra- and interexaminer reliability of mandibular measurements were very good for both the senior and junior examiners (Table 3). Very good intersession reliability was also found for both examiners (Table 4).

With the CBCT-based DRR approach, the effects of the identification of bony landmarks on the reliability of morphological parameter determination were studied for the first time in the literature without the effects of other factors such as superimposition of craniofacial structures, and positioning of the head during imaging. Very good intra- and inter-rater reliability were found for both examiners in measuring most of the mandibular parameters considered in the current study (Table 3). According to the Bland and Altman plots for each mandibular parameters of the inter-rater, there were systematical biases between examiners on most parameters, except Go-Pog, Cd-Go and Cd-CP (Fig. 3). This result means these parameters have more repeatability and reproducibility between examiners. In the cephalogram, the positions of Go, Pog, Cd, and CP are actually easy to identify which leads to the results which showed very good reliability between sessions for both examiners (Table 4). The only exception was CdP-GoP measured by the junior examiner, which showed only good intra-, inter-rater, and intersession reliability. One reason for this reduced reliability was related to the difficulty in the identification of the most posterior protruding point of the ramus (GoP). More extensive experience in identifying this point would be necessary for a very good reliability. Overall, the current results suggest that most of the mandibular parameters can be measured very reliably from cephologram regardless of trials, examiners, and measurement sessions.

The current study used the line segments defined by two anatomical landmarks on the mandible and the angles between the line segments to describe the morphology of the mandible. This approach better reflected common clinical descriptions. For example, the mandibular length was described by Cd-Gn, ramus length by Cd-Go, corpus length by Go-Pog, and the goion angle by Cd-Go-Gn, etc. This is in contrast to many previous studies in which only the reliability of the identification of single anatomical landmarks was studied.[10,11] A more recent study did consider the reliability of line segments similar to the three of the parameters considered in the current study, namely Cd-Gn, Cd-Go, and Go-Pog.[25] They found ICC values for Cd-Gn, Cd-Go, and Go-Pog to be 0.82, 0.81, and 0.58 respectively by orthodontics based on real life lateral cephalograms. The corresponding values were 0.96, 0.88, and 0.92 respectively in the current study (Table 3). It is noted that with real life cephalograms the effects of other factors such as superimposition of craniofacial structures, and positioning of the head during imaging could not be excluded in the analysis by Ongkosuwito et al.[25] Therefore, the differences in the ICC values between the two studies may be attributed to the effects from factors other than the variations of the manual identification of the landmarks. Therefore, the current reliability values can be regarded as the upper bound of the determination of the morphological parameters via manual identification of the anatomical landmarks on cephalograms.

The CBCT-based DRR approach adopted in the current study has been shown to be useful in determining the intra-, inter-rater, and intersession reliability of morphological measurements of the mandible. In the current study, the mandible was positioned at the neutral position where the principle axis of the imaging system passed precisely through the two condyles and the median plane at a fixed distance from the image plane. Therefore, the effects of only the variability of the manual identification on the morphological measurements could be studied. Although this does not include the effects of all the other factors found in real life images, the obtained reliability values are considered the upper bounds. The current approach will be useful for further studies examining one by one the effects of other factors such as malpositioning of the head during imaging, and the real life reliability for cephalogram-based measurements.

In conclusion, the current study showed that very good intra-, inter-rater, and intersession reliability in measuring mandibular morphological parameters could be achieved via manual identification of the anatomical landmarks without the effects of factors such as malpositioning of the head during imaging. Further investigations using the current DRR-based approach will be needed to evaluate the individual effects of these other factors on the morphological measurements.

Conflicts of interest

The authors have no conflicts of interest relevant to this article.

References

1. Ye R, Wang S, Pei J, Zhao M. Cephalometric analysis of the relationship between occlusal plane and sagittal position of the mandible. *WCJS* 2012;30:610—4.
2. Nijkamp PG, Habets LLMH, Aartman IHA, Zentner A. The influence of cephalometrics on orthodontic treatment planning. *Eur J Orthodont* 2008;30:630—5.
3. Hagg U, Attstrom K. Mandibular growth estimated by four cephalometric measurements. *Am J Orthod Dentofac* 1992; 102:146—52.
4. Kohjitani A, Miyawaki T, Miyawaki S, et al. Features of lateral cephalograms associated with difficult laryngoscopy in Japanese children undergoing oral and maxillofacial surgery. *Pediatr Anesth* 2013;23:994—1001.
5. Naragond A, Kenganal S, Sagarkar R, Kumar S, Sugaradday. Diagnostic limitations of cephalometrics in orthodontics—a review. *JDMS* 2012;3:30—5.
6. Athanasiou AE. Orthodontic cephalometry. *Am J Orthod Dentofac* 1997;111:458—9.
7. Major PW, Johnson DE, Hesse KL, Glover KE. Landmark identification error in posterior anterior cephalometrics. *Angle Orthod* 1994;64:447—54.
8. Ahlqvist J, Eliasson S, Welander U. The effect of projection errors on cephalometric length measurements. *Eur J Orthodont* 1986;8:141—8.
9. Na KC, Yoon YJ, Kim KW. A study on the errors in the cephalometric measurements. *Korean J Orthod* 1998;28:75—83.
10. Lagravere MO, Low C, Flores-Mir C, et al. Intraexaminer and interexaminer reliabilities of landmark identification on digitized lateral cephalograms and formatted 3-dimensional cone-beam computerized tomography images. *Am J Orthod Dentofac* 2010;137:598—604.
11. Chen MH, Chang JZC, Kok SH, et al. Intraobserver reliability of landmark identification in cone-beam computed tomography-synthesized two-dimensional cephalograms versus conventional cephalometric radiography: a preliminary study. *J Dent Sci* 2014;9:56—62.
12. Vishwanath AE, Sandesh SP, Nandini SN, Neelima A. CBCT — An Advanced Diagnostic Tool for Orthodontics and Other Specialties in Dentistry — A Systematic Review. Available at, http://orthocj.com/2012/09/cbct-an-advanced-diagnostic-tool-for-orthodontics-and-other-specialties-in-dentistry-a-systematic-review; Oct 2012 [accessed 07.07.14].
13. Amer Acad Oral M. Clinical recommendations regarding use of cone beam computed tomography in orthodontics. Position statement by the American Academy of Oral and Maxillofacial Radiology. *Oral Surg Oral Med Oral Pathol* 2013;116: 238—57.
14. Garcia Silva MA, Wolf U, Heinicke F, Bumann A, Visser H, Hirsch E. Cone-beam computed tomography for routine orthodontic treatment planning: a radiation dose evaluation. *Am J Orthod Dentofac* 2008;133:640.e1—5.
15. Kumar V, Satheesh K. Applications of cone beam computed tomography (CBCT) in implant treatment planning. *JSM* 2013; 1:1008.
16. Benavides E, Rios HF, Ganz SD, et al. Use of cone beam computed tomography in implant dentistry: the International Congress of Oral Implantologists Consensus Report. *Implant Dent* 2012;21:78—86.
17. Kuo CC, Lu HL, Lu TW, et al. Effects of positioning on radiographic measurements of ankle morphology: a computerized tomography-based simulation study. *Biomed Eng Online* 2013; 12:1—16.
18. Wu CH, Lin CC, Lu HL, Lu TW, Yeh LS. Effects of pelvic and femoral positioning on canine Norberg angle measurements and testeretest reliability: a computed tomography-based simulation study. *Biomed Eng-App Bas C* 2014;26. 1450076.
19. Chen CC, Lin CC, Lu TW, Chiang H, Chen YJ. Feasibility of differential quantification of 3D temporomandibular kinematics during various oral activities using a cone-beam computed tomography-based 3D fluoroscopic method. *J Dent Sci* 2013;8:151—9.
20. Lin CC, Lu TW, Shih TF, Tsai TY, Wang TM, Hsu SJ. Intervertebral anticollision constraints improve out-of-plane translation accuracy of a single-plane fluoroscopy-to-CT registration method for measuring spinal motion. *Med Phys* 2013;40:031912.
21. Lin HS, Chen YJ, Li JD, Lu TW, Chang HH, Hu CC. Measurement of mandibular growth using cone-beam computed tomography: a miniature pig model study. *PloS one* 2014;9:e96540.
22. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychol Bull* 1979;86:420—8.
23. Altman DG. *Practical Statistics for Medical Research*. London: CRC Press, 1990.
24. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;1:307—10.
25. Ongkosuwito EM, Dieleman MM, Kuijpers-Jagtman AM, Mulder PG, van Neck JW. Linear mandibular measurements: comparison between orthopantomograms and lateral cephalograms. *Cleft Palate-Cran J* 2009;46:147—53.